The Influence of Blinds on Temperatures and Air Flows within Ventilated Double-Skin Façades

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ABSTRACT

Ventilated façades have become an increasingly employed feature in the design of low energy buildings over recent years in that they offer the attractive features of a conventional glass façade but without the thermal disadvantages. These façades consist of a double skin surface, the outer layer of which is of toughened glass, and the inner layer of which usually comprises conventional double-glazing, behind which is the occupied space.

The cavity formed by the outer and inner layers is ventilated, and frequently contains a blind. This blind, together with the cavity ventilation, provides a means to control the heat transfer across the façade, in terms of solar gain transmission and recovery of heat lost from the interior.

A three-year project, funded by the UK's Engineering and Physical Sciences Research Council (EPSRC), has investigated the thermal and airflow performance of ventilated façades. A series of parametric experiments have been performed using the Large Scale Solar Simulator at Loughborough University. Results from these experiments have been used to validate models of airflow and thermal behaviour developed at De Montfort University. Advice on practical application and industrial practice has been provided by Arup Research and Development and IT Power. The result of the research is an improved understanding of the thermal and air flow behaviour of such ventilated double skin façades.

The effects of external conditions, solar irradiation and exterior air temperature, on double skin façades with differing internal characteristics are presented and analysed in this paper. In particular, the effect of the blind blade angle on cavity temperatures and ventilation air flows will be reported, together with an outline of the guidance that is now emerging to assist designers of such façades.

INTRODUCTION

Detailed measurements of the thermal performance of building elements are essential in the validation of models used for performance prediction. A collaborative project funded by the UK's Engineering & Physical Sciences Research Council (EPSRC) has recently been completed. The focus of this project was a detailed investigation of the performance of double skin façades, which are an increasing feature of many commercial and public buildings. Such façades typically consist of an outer layer of toughened glass, a double glazed inner layer and a ventilated cavity that frequently includes a solar control device, typically a venetian blind [1]. An objective of this research was to measure and provide a comprehensive data set detailing air and surface temperatures, together with air flow rates, so as to provide a practical resource for further research and for use by building designers.

Facilities for providing detailed measurements of such building façade elements under controlled conditions are hard to find. Most testing to date has been conducted outdoors where there is little or no control of the key environmental factors [2, 3]. Further development and characterisation of double skin façades requires good control of the test conditions, not only of the solar radiation striking the façade surface, but also of the thermal environments that affect the façade surfaces both externally ('outdoors') and internally ('indoors'. Such a facility is available at Loughborough, and has been used to provide the experimental results reported here. Key characteristics of the specially designed Large Scale Solar Simulator, are also presented.

Prior to carrying out the detailed tests, wide ranging consultation with the designers and manufacturers of building façades was undertaken. As a result, the more conventional façade element comprising a single storey 'box-window' was selected for investigation [1]. In this respect, a full sized double skin façade incorporating a sun-shading blind was constructed and installed in the solar simulator for investigation of its performance . As the majority of practical installations of the double skin façade utilise natural ventilation, the work has concentrated on this more challenging situation of buoyancy-driven flow in the façade cavity.

This paper describes details of the experimental conditions, together with the characteristics of the test facility and the tested façade element. Test results showing façade temperatures and airflow profiles and how they depend on the climatic conditions and the blind blade angles are presented.

THE LARGE SCALE SOLAR SIMULATOR AND THE DOUBLE SKIN FAÇADE

Large Scale Solar Simulator

Numerous details of the simulator have been reported in Mei et al[4], but are given again here for convenience. The large scale solar simulator installed at Loughborough University essentially provides a source of artificial solar radiation of acceptable spectrum and uniformity for irradiating a test element surface. In addition, the simulator provides for two separately conditioned thermal environments on either side of the test element. In this way, the thermal behaviour of building-integrated test elements, as if bounded by 'outdoor' and 'indoor' environments, can be effectively addressed. The solar radiation is provided by fifteen Sol 1200 lamps manufactured by Honle UV(UK) Ltd. The lamps are capable of producing a natural sunlight spectrum to D65 standard, at an air mass ratio of 1.5, and can deliver an irradiance upon a test surface of up to 1000W/m² with a uniformity to within ±10%. A combination of mesh attachments can be used to reduce the 1000W/m² peak irradiance value in steps of 200W/m² down to a minimum of approximately 200W/m², without spectral alteration.

The solar simulator is designed to test elements up to 2.5m in length and 1.5m in width. It is also possible to ventilate the test element both on its front face (to simulate wind) or through an internal cavity within the element, as required. This can consist of natural or mechanical convection, depending upon the nature of the element being tested.

The environment that adjoins the front irradiated surface of the test element corresponds to the 'outdoor' ambient condition. Air conditioning of the test laboratory space was used to maintain the required outdoor ambient environment within the temperature range 12°C to 30°C. The environment that adjoins the rear of the tested element corresponds to the 'indoor' ambient condition, such as a room or office. A rectangular shaped enclosure attached to the rear of the test element was used to produce the rear environmental conditions. The air and mean radiant temperatures within the rear enclosure are mostly maintained equal in the tests reported here but can be independently controlled if required. Air can also flow through the rear enclosure if required so as to generate known heat transfer conditions.

The solar simulator facility has been designed specifically for testing multifunctional façade elements but can also be used for other, more conventional, components such as solar thermal collectors, curtain walls, roof lights and for PV applications. Fig 1 shows the arrangements of the lamps in the solar simulator.

Fig. 1 Large Scale Solar Simulator, showing lamp array.

THE TEST FAÇADE AND ITS COMPONENTS

The test façade element was custom-built using materials and dimensions that closely resembled a typical single-storey ('box-window') commercial façade design. To facilitate experimental testing and access, both the inner and outer skins of the façade were constructed as door assemblies. The outer skin of the designed double skin façade is a single glass door which is 144cm wide and 206cm high comprising an aluminium frame and 12mm thick toughened clear glass. The glass area is 128cm × 191cm. The outer skin of the façade was designed to be opened and closed for easily installing the measurement devices and for changing the blind positions. Air leakage was minimised by sealing the façade doors with rubber strip seals. Both the air intake and exhaust of the double skin façade are designed as a commercial grille arrangement to permit air flow through the façade cavity. The grilles are of height 24cm and width 145cm. Each grille has three spaces for air ingress and egress, each space being 4.5cm high. In commercial façades, wire meshes are installed horizontally at the bottom and top of the façade cavity to prevent birds getting into the façade. These are included in the customised test section for authenticity of design. The size of the mesh 'hole' is 2.5cm square.

The façade inner skin consists of another door, fitted with double glazing housed within an aluminium frame. The glazing cross section comprises two panes of low-e toughened clear glass each 6mm thick, separated by an air cavity of width 16mm. The dimensions of the inner skin are 138cm × 200cm and the glass area is 122cm × 185cm. Fig 2 shows photographs of the constructed double skin façade where the outer skin can be opened for installing measurement devices.

a) b)

Fig 2 The Tested Double Skin façade: a) outer door closed; b) outer door open

SUN-SHADING BLINDS

The sun-shading devices commonly used in practice and installed for these experiments are Venetian type blinds, These were purchased from the Krülland Company in Germany. This type of blinds can be motor driven. The blinds tested are made of aluminium and the blade width is 8cm (total blind dimensions 2.1 m high by 1.45 m wide). The colours of blinds selected for testing were white (reflectance = 0.762), and dark brown (reflectance = 0.079). In Fig 3. both colours of blinds can be seen in the cavity of the double skin façade.

a) b)

Fig. 3 The blinds installed in the façade cavity:
(a) dark brown ('spartbrown'); (b) white

MEASUREMENTS

TSI air velocity transducers, based on anemometry, were selected to measure air velocities within the ventilated cavity. The TSI Omni directional Model 8475 offers accurate measurements at low velocities from 0.05 to 0.5m/s and is suitable for unknown or varying flow direction. The accuracy of Model 8475 is ±3.0% of reading over the temperature range 20°C to 26°C, outside this range, and within temperature compensation range, an additional reading error of 0.5% per °C must be added to the measured values.
Cable to the connector

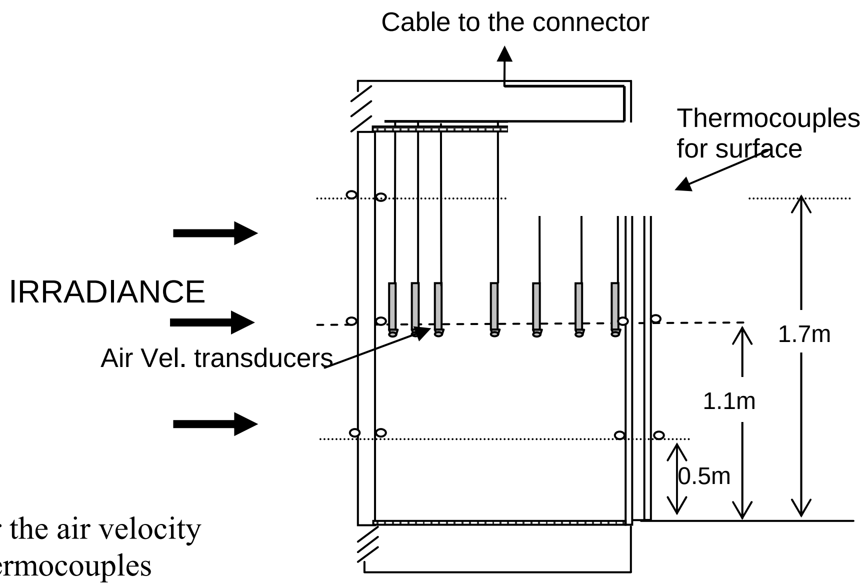


Fig. 4 Positions for the air velocity transducers and thermocouples (side cross-sectional view of cavity)

Seven such air velocity transducers were used for the measurements, and to each velocity transducer a calibrated type-T thermocouple was attached to provide co-located airflow and air temperature data. The transducers were suspended vertically in the cavity with the probes facing the upward air flow. For most of the experiments, the transducers were located at the middle height of the façade cavity (1.1m from the bottom of the façade). The distribution of air velocity transducers and thermocouples can be seen in Fig. 4.

In total, twenty two T-type thermocouples were used to measure the façade surface temperatures and the cavity air temperatures. For measuring the surface temperatures, twelve thermocouples were attached to the glass and covered with thermocouple pads to shade the thermocouples from the direct solar radiation. Pad emissivities matched that of the surrounding surface. For measuring the cavity air temperature, seven thermocouples, were attached to the air velocity transducers; the thermocouples were located about one centimetre distance downstream of the velocity transducer probe head.

A Kipp & Zonen CM3 pyranometer (0-2000W/m² = 0-0.5V) connected to the data logging system was used to measure the radiation on the façade outer skin surface. Table 1 gives the measured irradiance values corresponding to the nominal irradiance values which can be selected by choice of mesh in front of the lamps.

Table 1 Measured irradiance corresponding to nominal irradiance.

Nominal	800W/m²	600W/m²	400W/m²	200W/m²
Measured	715W/m²	540W/m²	360W/m²	187W/m²

In the experiments, the nominal irradiances were varied from 200W/m² to 800W/m² by changing the mesh attachments. However, in all results, the measured irradiance values were used and quoted.

The data acquisition and logging (DAQ) system for the Large Scale Solar Simulator is PC based and employs National Instruments (NI) Labview software, with two internally fitted NI data acquisition boards.

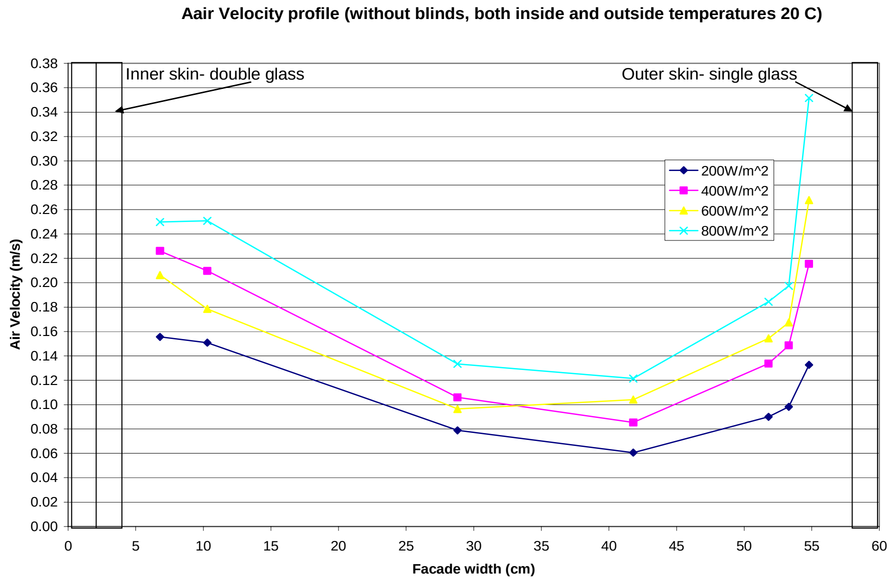
EXPERIMENTAL RESULTS

Test without blinds

Testing of the double skin façade without blinds was performed over a range of controlled climate conditions.

Tests have been carried out under the following measured irradiance values: 187W/m², 360W/m², 540W/m² and 715W/m² For each irradiance, three values for the test room air temperatures ('outdoor' air temperature or T_{room}) were set: 12°C, 20°C and 30°C, respectively. A total of twelve environmental conditions were tested for the double skin façade. The plenum air temperature ('indoor' air temperature, or T_{box}) was set to 20°C for all the experiments. The cavity width was fixed at 550mm for all experiments. Typical results are shown in Fig. 5 for profiles of the air velocity and façade temperatures (surfaces and cavity air) at four irradiances and at 20°C for both 'indoor' and 'outdoor' conditions. It is evident that the cavity air velocity and façade temperatures increase with increasing values of the irradiance. It is also clear that the air speed is faster nearer the surfaces of the glazing that bound the cavity.

In order to better see the impacts of varying conditions, air velocity and façade temperature were plotted as a function of the irradiance for each data set as shown in Fig. 6. It appears that the increase of the air velocity and the local façade temperatures are more or less directly proportional to the irradiance. For both air velocity and temperature, each set of data gives slightly different gradients.



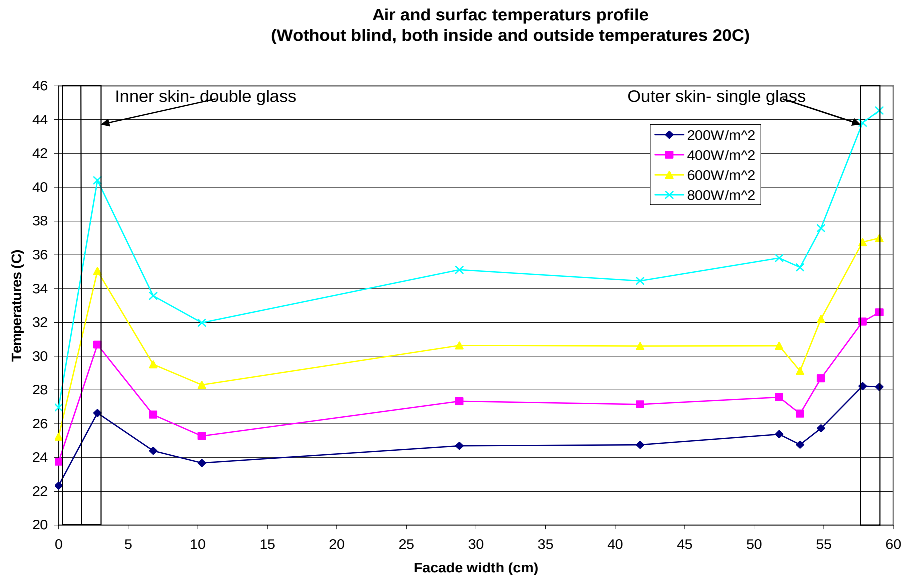


Fig. 5 The profile of the air velocity and the façade temperatures across the façade cavity

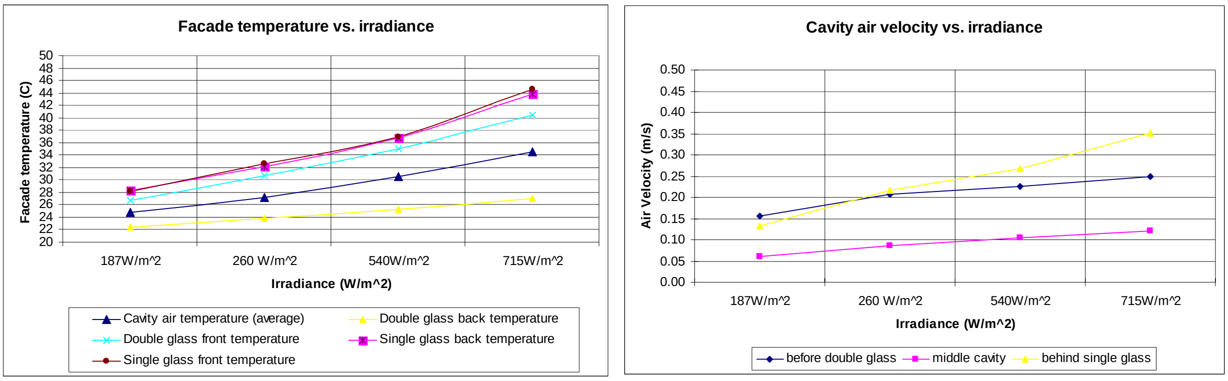


Fig. 6 Façade temperature and cavity air velocity increase vs. solar irradiance; Both 'outdoor' and 'indoor' air temperatures are fixed at 20°C.

In a similar manner, the effect of 'outdoor' temperature on the cavity air velocity and façade temperature is shown in Fig. 7. In this graph, the comparison of the air velocities in the cavity and the temperatures of the façade (surfaces and cavity air) for three different temperatures of the 'outdoor' air at a fixed irradiance of 715W/m² are presented. Façade air velocity and façade temperatures appear to be proportional to the 'outdoor' air temperature.

It is noticed that the double glass back temperature (inner skin back) was dominated by the controlled 'indoor' temperature which was at 20°C. Therefore, for the effects of either irradiance or outdoor air temperature, the double glass back temperature tends to be low with only small gradients evident. From Figs. 6 and 7, it also can be seen that the cavity air velocity was affected strongly by the irradiance rather than the outdoor air temperature.

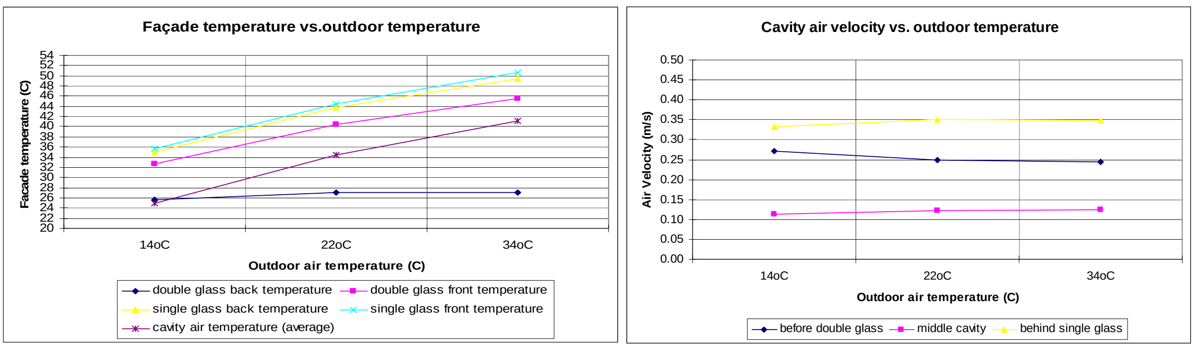
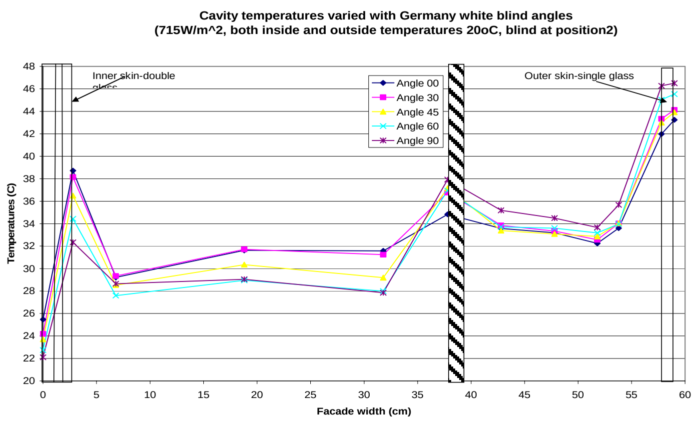


Fig. 7 Façade temperature and cavity air velocity increase vs. outdoor temperature; the irradiance is set at 715W/ m²

TESTS WITH SUN-SHADING DEVICE (BLINDS)

Tests with the blinds within the cavity of the double skin façade were performed to investigate several effects, including the effects of blind blade angle on cavity airflow and thermal behaviour. The angle of the blind blade is an important factor for the heat transfer through the façade cavity, and data on observed behaviour is needed based on parametric testing in controlled conditions. These data are presented in this paper.

The tests for the effects of blind blade angles were carried out at the fixed conditions of 715W/m² irradiance and 20°C temperature for both 'indoor' and 'outdoor' situations. The blind colour is white and the blind was located at one third of the cavity width as measured from the outer skin. The blade angles were set at 0, 30, 45, 60 and 90 degrees, where 0 and 90 degrees relate to the blinds being fully open or fully closed, respectively. In Fig. 8, the measured air velocities of the cavity and the façade temperatures are displayed as profiles across the cavity width for the blind blade angles. In Fig. 9, the cavity air velocities and the façade temperatures are plotted as a function of the blind blade angles. As the blind effectively separates the façade cavity into two vertical chambers, the effect on the cavity air velocity and the façade temperatures will be considered as two parts: in front of the blind and behind the blind. From both Fig. 8 and 9, it can be seen that the temperatures of the façade surface and cavity air in front of the blind increase as blind blade angle increases until the fully closed position is reached (90 degrees), as well as the surface temperature of the blinds themselves. Behind the blind, the temperatures for the surface and the cavity air decrease as blind blade angle increases. It is clear that with the blade at 0 degrees (fully open), more radiation energy transfers to the back chamber and causes the higher temperature in the chamber behind the blind. When the blade is at 90 degrees (fully closed), the blind absorbs more radiation energy and its surface temperature rises. At the same time, the blind reflects more energy to the front chamber and the single glass (outer skin) to increase the temperature of both the air and the surfaces.



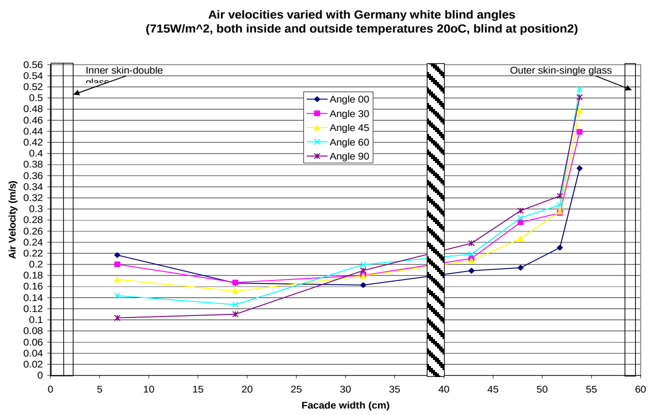


Fig. 8 The profile of air velocity and the façade temperatures crossing the façade cavity

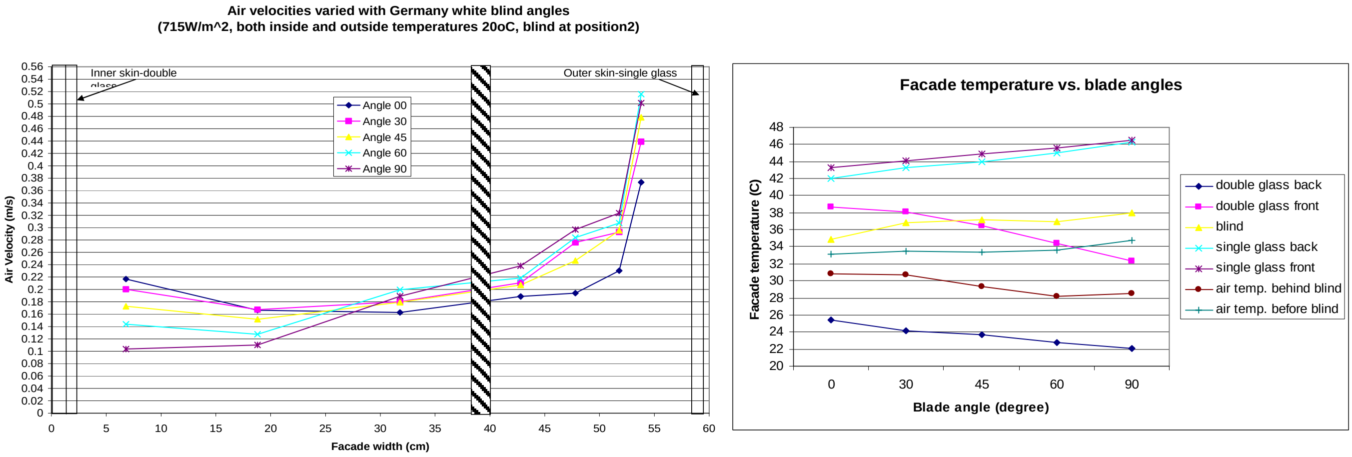


Fig 9. Façade temperatures and cavity air velocity   vs. blind blade angles

CONCLUSIONS

An outline description has been presented of a new facility installed at Loughborough University for the testing and development of building ventilated façade elements. A series of parametric experiments have been carried out for testing the performance of these façades under controlled conditions using a large scale solar simulator.

One series of tests involved a section of double skin façade with a common type of solar shading device (venetian blinds) located between the two skins. Test results for the air flow and façade temperatures have been presented. The effects of the irradiance and outdoor air temperature were shown to affect the air velocity and façade temperatures, and thus the façade thermal performance. Furthermore, the effect of the blade angles of the shading device located in the naturally ventilated cavity was presented . The presence of the shading device within the cavity can be considered to separate the cavity into two vertical chambers, in front of and behind the blinds. It is concluded that the blinds have a significant influence on the thermal and airflow performance of the façade. If the sun-shading device is fully closed, the 'front chamber' of the cavity and the shading element itself will have higher temperatures than if it is opened. In contrast, the temperatures behind the sun-shading device will be higher if the sun-shading device is fully opened. Whilst these findings might at first sight appear intuitive and unremarkable, it is important to note that the behaviour has been related parametrically to specific changes in conditions, has revealed trends in performance, and thus constitute a useful data resource, as well as being an important aid to designers. These findings were obtained under well-controlled conditions in an experimental facility that incorporates a representative section of double-skin façade. This facility remains available for further testing across a wide range of parameters (blind colour and position within cavity, cavity width), and these will be reported in due course. It is further concluded that the large scale solar simulator is a valuable facility for testing the solar thermal performance of building components and can provide realistic and meaningful results.

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